



A High Resolution Statistical Characterization of  
Fading on Meteor Communication Channels

Jay A. Weitzen  
Jens C. Ostergaard  
Siu Wing Li

University of Lowell  
Center for Atmospheric Research  
450 Aiken Street  
Lowell, Massachusetts 01854

November 1990

Scientific Report No. 4

Approved for public release; distribution unlimited.

GEOPHYSICS LABORATORY  
AIR FORCE SYSTEMS COMMAND  
UNITED STATES AIR FORCE  
HANSOM AIR FORCE BASE, MA 01731-5000

DTIC  
ELECTED  
MAY 14 1991  
S B D

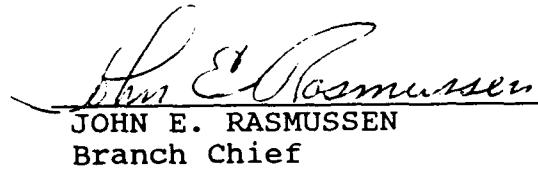
DTIC REPRODUCED BY

91 5 14 084

"This technical report has been reviewed and is approved for publication"



ALAN D. BAILEY  
Contract Manager



JOHN E. RASMUSSEN  
Branch Chief

FOR THE COMMANDER



ROBERT A. SKRIVANEK  
Division Director

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify GL/IMA, Hanscom AFB, MA 01731. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

## UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)  ULRF-469/CAR		5. MONITORING ORGANIZATION REPORT NUMBER(S)  GL-TR-90-0329			
6a. NAME OF PERFORMING ORGANIZATION  University of Lowell	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION  Geophysics Laboratory			
6c. ADDRESS (City, State, and ZIP Code)  Center for Atmospheric Research 450 Aiken Street Lowell, MA 01854		7b. ADDRESS (City, State, and ZIP Code)  Hanscom AFB Massachusetts 01731-5000			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION  Geophysics Laboratory	8b. OFFICE SYMBOL (If applicable)  LID	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  F13628-88-K-0004			
8c. ADDRESS (City, State, and ZIP Code)  Hanscom AFB Massachusetts 01731-5000		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO.  62101F	PROJECT NO.  4643	TASK NO.  10	WORK UNIT ACCESSION NO.  AI
11. TITLE (Include Security Classification) A High Resolution Statistical Characterization of Fading on Meteor Communication Channels					
12. PERSONAL AUTHOR(S) Jay A. Weitzen, Jens C. Ostergaard, Siu Wing Li					
13a. TYPE OF REPORT Scientific No. 4	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) November 1990		15. PAGE COUNT 36	
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Fading, Sporadic-E Propagation, Meteor Propagation, Meteor Trail, Bandwidth, Signal-to-Noise, Trail Duration			
FIELD	GROUP	SUB-GROUP			
19. ABSTRACT (Continue on reverse if necessary and identify by block number)  This document describes the second part of a statistical study of fading on meteor communication channels based on data obtained from the Geophysics Laboratory's High Latitude Meteor Scatter Test Bed. In this experiment the sampling rate is increased from 100 Hz to 2000 Hz to provide resolution of 0.5 ms. Trails at 45 MHz from both the Sondrestrom Thule, and Sondrestrom Narsarsuaq links are considered. Trails are classified as underdense or overdense using a modified version of the GL automatic classification routine. Trails are then analyzed for fades with depths exceeding 3, 6, and 9 dB relative to a 10 dB Signal-to-Noise threshold. Signal-to-noise ratios are considered relative to bandwidths which vary from 4.8 kHz to 128 kHz. Statistics are computed as a function of frequency, time of day, and trail type for the first D seconds of a trail, where D = 50, 100, 200, 400, and 600 ms. The experiment considers fades with 1 ms minimum duration with a resolution of 0.5 ms.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Alan D. Bailey			22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL GL/LID	

## TABLE OF CONTENTS

	Page
1.0 INTRODUCTION	1
2.0 STATISTICAL CHARACTERIZATION OF FADING ON METEOR CHANNELS	2
2.1 Experiment Description	2
2.1.1 Definition of a Fade	4
2.2 Data Analysis	5
3.0 DISCUSSION	24
4.0 REFERENCES	26

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/ _____	
Availability Codes	
Dist	Avail and/or Special
A'	

## LIST OF FIGURES

Figure No.		Page
1	Meteor Trail Fade Methodology	3
2	Sondrestrom-Narsarsuaq Link; 50 ms Duration	6
3	Sondrestrom-Thule Link; 50 ms Duration	7
4	Sondrestrom-Narsarsuaq Link; 100 ms Duration	9
5	Sondrestrom-Thule Link; 100 ms Duration	10
6	Sondrestrom-Narsarsuaq Link; 200 ms Duration	11
7	Sondrestrom-Thule Link; 200 ms Duration	12
8	Sondrestrom-Narsarsuaq Link; 400 ms Duration	13
9	Sondrestrom-Thule Link; 400 ms Duration	14
10	Sondrestrom-Narsarsuaq Link; 60 ms Duration	15
11	Sondrestrom-Thule Link; 600 ms Duration	16
12	Cumulative Probability Distribution Function; 50 ms Duration	19
13	Cumulative Probability Distribution Function; 100 ms Duration	20
14	Cumulative Probability Distribution Function; 200 ms Duration	21

## LIST OF FIGURES (Continued)

Figure No.		Page
15	Cumulative Probability Distribution Function; 400 ms Duration	22
16	Cumulative Probability Distribution Function; 600 ms Duration	23

## LIST OF TABLES

Table No.		Page
1	Summary of Results for July 1990: Sondrestrom-Narsarsuaq Link	17
2	Summary of Results for April 1990: Sondrestrom-Thule Link	18
3	Summary of Results for Low Resolution Experiment	18
4	Comparison of High Resolution and Low Resolution Data for 100 ms Duration Trails	24
5	Summary of High and Low Resolution Measurements for Trails of 200 ms Duration	25

## 1.0 INTRODUCTION

Phase I of the meteor scatter fading study [Weitzen et al., 1990a] considered the effects of fading events (minimum duration 20 ms with a 10 ms resolution) on meteor scatter communication. Data showed that for the most part the effect of fading was not significant (less than 10-15 percent of the trails exhibited fading) at trail durations less than 200 ms.

The objective of Phase II of the experimental program is to improve the resolution by increasing the sampling rate from 100 to 2000 Hz to observe whether the trends remain the same. The Phase I report has a detailed description of the equipment and the theory of the fading mechanisms observed on the meteor channel.

## 2.0 STATISTICAL CHARACTERIZATION OF FADING ON METEOR CHANNELS

### 2.1 Experiment Description

The objective of this effort in contrast to previous channel characterization efforts is to accept the fact that there are a number of mechanisms which can cause fading and to statistically characterize the probability of fade occurrence. Data were collected at 45 MHz on the 1210 km Sondrestrom-Thule link during April 1990 and on the 690 km Sondrestrom-Narsarsuaq link during July 1990. Both links are operated as part of the Air Force Geophysics Laboratory High Latitude Meteor Scatter Test Bed. In this experiment, the sampling rate was increased from 100 Hz to 2000 Hz and the system bandwidth was increased from 50 Hz to 1000 Hz.

Data from the links are returned to the Geophysics Laboratory for automatic analysis. Special versions of the automatic classification routine and the automated data analysis routines were developed to analyze the larger data records. Four second data records consisting of 8000 data points are computer classified as either sporadic-E propagation or meteor propagation and each meteor trail identified is further classified as underdense or overdense using the technique described in the BMO Criteria Report [1990] and other documents [Weitzen and Tolman, 1986; Weitzen, 1990].

As with the previous study, fading is defined according to the following methodology illustrated in Figure 1.

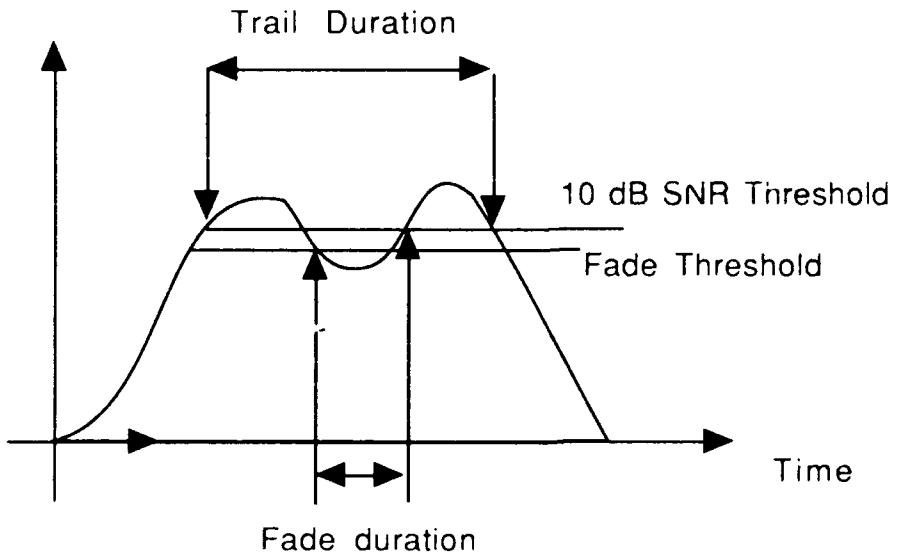


Figure 1. Meteor Trail Fade Methodology

A trail event begins when the received signal to noise ratio first exceeds 10 dB ( $s + n/n = 10.4$  dB) relative to the defined bandwidth. The effective system bandwidth is 1000 Hz. Bandwidths considered for analysis are: 4.8, 8.0, 9.6, 19.2, 32.0, 64.0, 128.0 kHz. For example 10 dB SNR relative to a 8000 Hz bandwidth corresponds to a 19 dB SNR relative to the 1000 Hz system bandwidth.

Care must be exercised when interpreting the data from the higher resolution experiment because the system bandwidth has increased relative to the Phase I study. To illustrate the effect of increasing system bandwidth, consider the following example. In the Phase I study, at 8000 Hz effective bandwidth with 10 dB SNR in this bandwidth, the actual signal-to-noise ratio in the 50 Hz system bandwidth was on the order of 32 dB. Because of the high signal-to-noise ratio, it could be inferred with a high degree of certainty that a fade was due to a decrease in the channel gain rather than an increase in the noise level. In the Phase II program, the bandwidth is increased by a factor of 20 so that the signal-to-noise ratio at a given effective

bandwidth is reduced by 13 dB relative to the Phase I experiment. For the 8000 Hz data rate considered as the baseline for analysis, the signal-to-noise ratio is on the order of 19 dB relative to the 1000 Hz system bandwidth. Assuming additive white Gaussian noise, independent from point to point, with a minimum 19 dB SNR, the probability that there will be a 3 dB or greater fade due to noise alone is on the order of  $4.0 \times 10^{-6}$  for each point. For a 50 ms trail the probability of a noise induced fade is on the order of 1 percent. For a 200 ms trail, the probability of a noise induced fade is on the order of 3 percent.

One other factor must be considered. It is well known that during the formation of a meteor trail, as the meteor transits the higher order Fresnel zones, alternating zones of constructive and destructive interference will be observed. With a resolution of 10 ms or less, this phenomenon may not be observed, however with the increased system bandwidth, it will be observed. To insure that noise induced fades are not considered, we will consider 6 and 9 dB fades in the analysis.

### 2.1.1 Definition of a Fade

When the trail event begins, the duration clock is started. For a trail to be counted towards the number of trails exceeding the signal level for the required duration, the signal must be above the required signal threshold D seconds after the trail event begins. For the given analysis trail durations of D = 50, 100, 200, 400, and 600 ms are considered.

A fade occurs when the signal-to-noise ratio drops below (10 - fade depth) dB and then the signal returns above the original 10 dB SNR threshold, all within the first D seconds from the beginning of the trail event. Fade depths considered are 3, 6, or 9 dB. A fade must be 1 ms or greater (2 or more data points) for it to be counted as a fade. This is done to minimize the effect of single point noise bursts. The definition of fading used in the analysis provides a data set in which the number of samples is independent

of the depth of the fade. Other definitions would not have this desirable characteristic.

The duration of a fade is measured from the time the signal threshold drops below the 3, 6, or 9 dB threshold to the time that it exceeds the original 10 dB SNR threshold. This is illustrated in Figure 1. Using this methodology, there can be more than one fade during the duration of a trail.

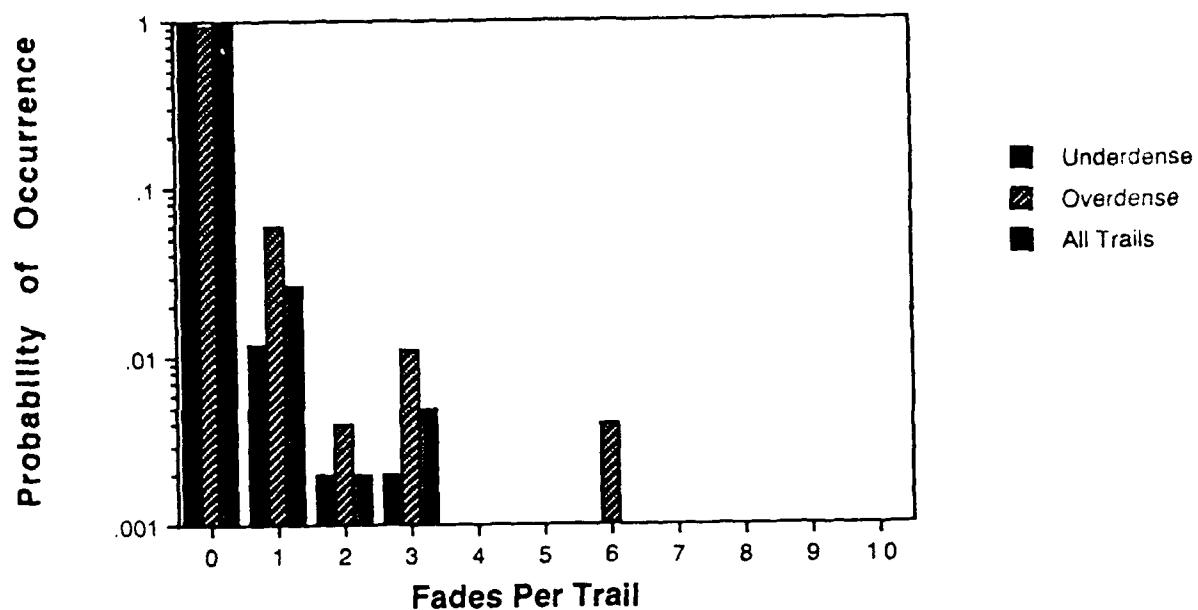
For each fade which is observed in the first D seconds of the trail, the duration is measured and recorded. For each trail the number of fades in the first D seconds ( $D = 50, 100, 200, 400, 600$  ms) and their durations are recorded. For this experiment data were collected at 45 MHz and analyzed as a function of trail type (underdense and overdense) and time of day. Figure 1 illustrates the definition of a fade used in the analysis.

## 2.2 Data Analysis

Data from the Sondrestrom-Thule link (1210 km) for the month of April 1990 and from the Sondrestrom-Narsarsuaq link (690) km for the month of July 1990 were selected for detailed analysis. In table form, statistics of fades at all bandwidths, durations, and fade depths are computed for each trail type. Since the number of tables exceeds 1000, we have selected for analysis in this report a data set which closely approximates the proposed SICBM scenario. Consider a data rate of 8000 bps. We consider the fading observed at depths of 6 and 9 dB. A 6 dB fade (SNR dropping below 4 dB) is assumed to be adequate to cause an outage.

We first consider the case of trails with 50 ms minimum duration and 10 dB SNR relative to the 8 kHz bandwidth. In the first plots, Figures 2 and 3, we present normalized histograms of the number of fades observed per trail versus the probability. For the case of 50 ms duration, with minimum resolution of 1 ms, less than 2 percent of all the trails for each data set show fading. On each plot, the size of the data sample, (U = underdense, O

**Month: July; BW: 8000 Hz; Duration: 50 ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**  
**Sample Size: U:584 O:269 A:853**



**Month: July; BW: 8000 Hz; Duration: 50 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**  
**Sample Size: U: 584 O: 269 A: 853**

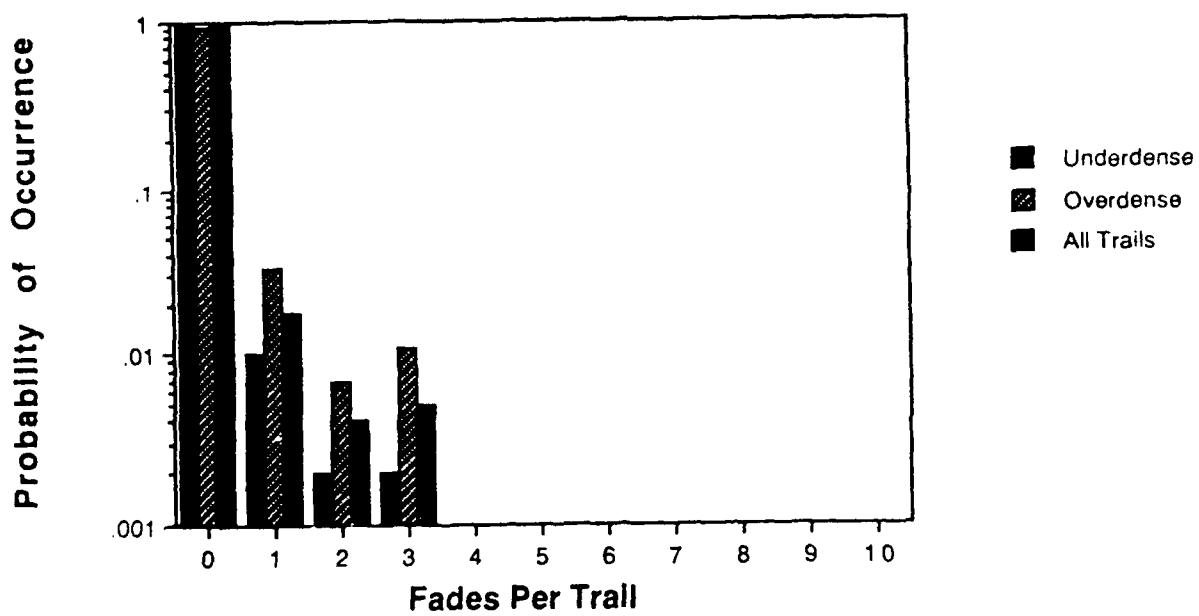
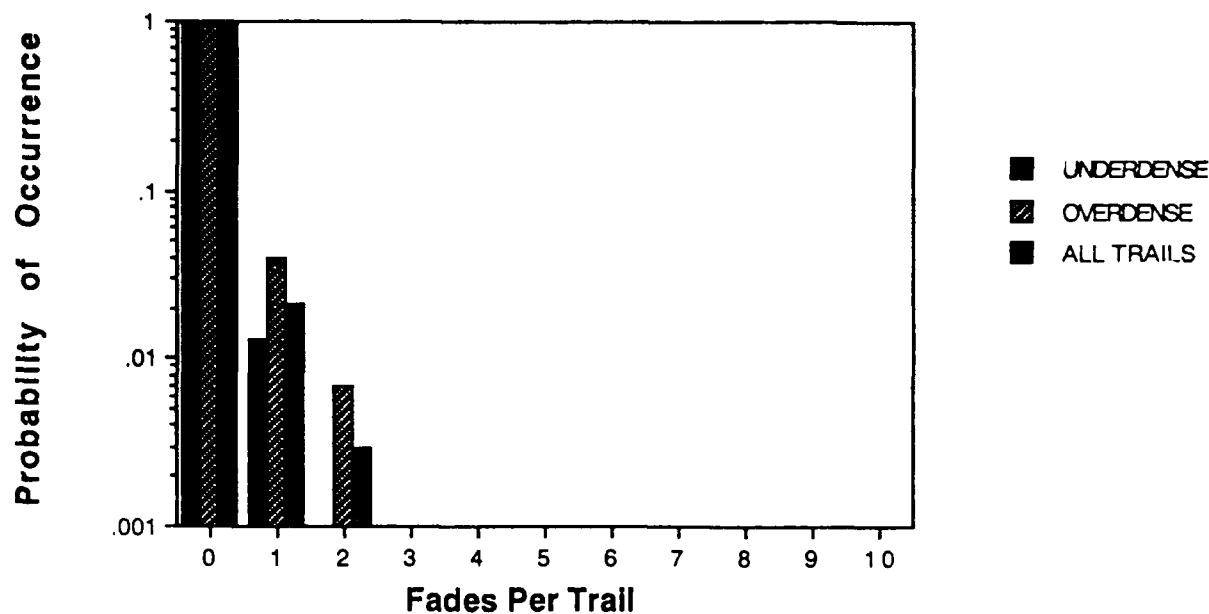


Figure 2. Sondrestrom-Narsarsuaq Link; 50 ms Duration

**Month: April; BW: 8000 Hz; Duration: 50 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km  
Sample Size: U:4037 O:1970 A:6007**



**Month: April; BW: 8000 Hz; Duration: 50 ms;  
Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km  
Sample Size: U: 4037 O:1970 A: 6007**

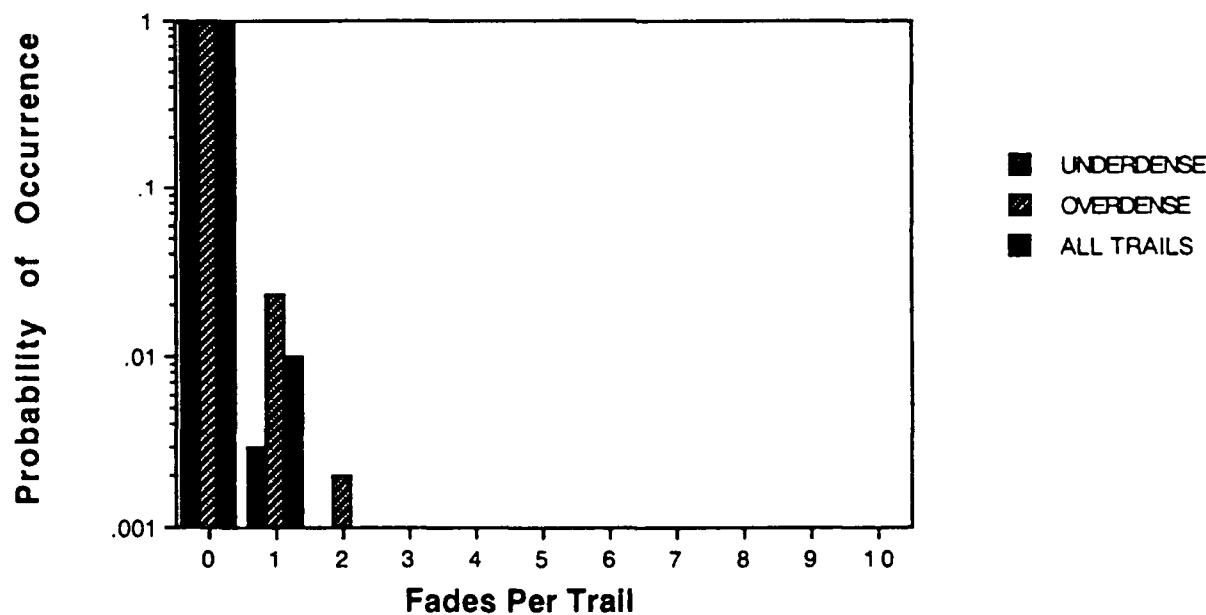


Figure 3. Sondrestrom-Thule Link; 50 ms Duration

= overdense, A = all trails) is included in the header. Data from both the 1210 and 690 km links are considered.

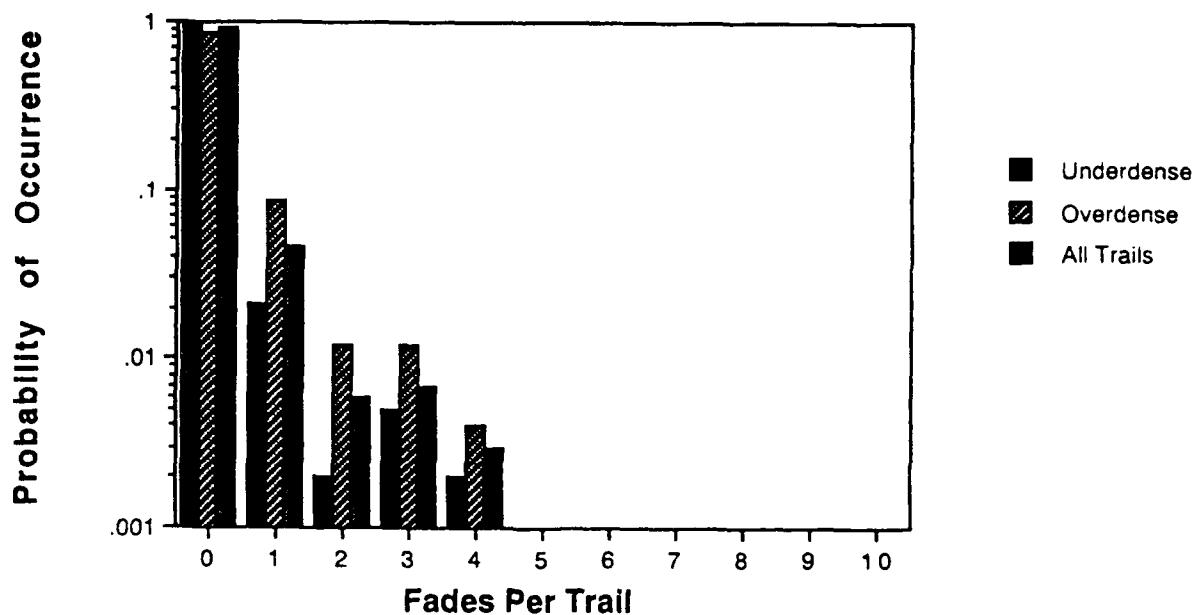
The next set of plots, Figures 4 and 5, consider the case of 100 ms trail durations. A trend emerges in the data which is consistent over the entire data set. Underdense trails tend to show less fading than overdense trails. At 100 ms duration, approximately 3-4 percent of all the trails examined have fades with a maximum depth exceeding 6 dB below the 10 dB threshold. As expected, fewer fades are observed at 9 dB than at 6 dB peak depth.

The next set of plots, Figures 6 and 7, cover the 200 ms trail durations. As the duration increases, the percentage of trails which show fading increases. The trend for the duration of fades to increase with depth continues. Two effects tend to influence the percentage of trails which are showing fading: 1) the percent of the data sample which is underdense is decreasing and 2) the percent of overdense trails which are fading is also increasing. At 200 ms, approximately 7 % of the trails are showing fades of depth 6 dB or greater.

At 400 ms trail duration, high altitude winds have had time to warp trails as described in Section 1 of the Phase 1 report. The percentage of trails which show fading increases. The percentage of trails which are also overdense increases. As the duration increases, the variation in the percentage of trails which are fading is around 15-20% at 45 MHz. Then plots are shown in Figures 8 and 9.

At 600 ms duration, the percentage of trails with fades is approaching 30%. At this long duration, wind induced warping will be common. Interleaving combined with error correcting coding would be very useful at the longer trail duration. Then plots are shown in Figures 10 and 11.

**Month: July; BW: 8000 Hz; Duration: 100 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km  
Sample Size: U: 424 O:245 A: 669**



**Month: July; BW: 8000 Hz; Duration: 100 ms;  
Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km  
Sample Size: U: 424 O:245 A:669**

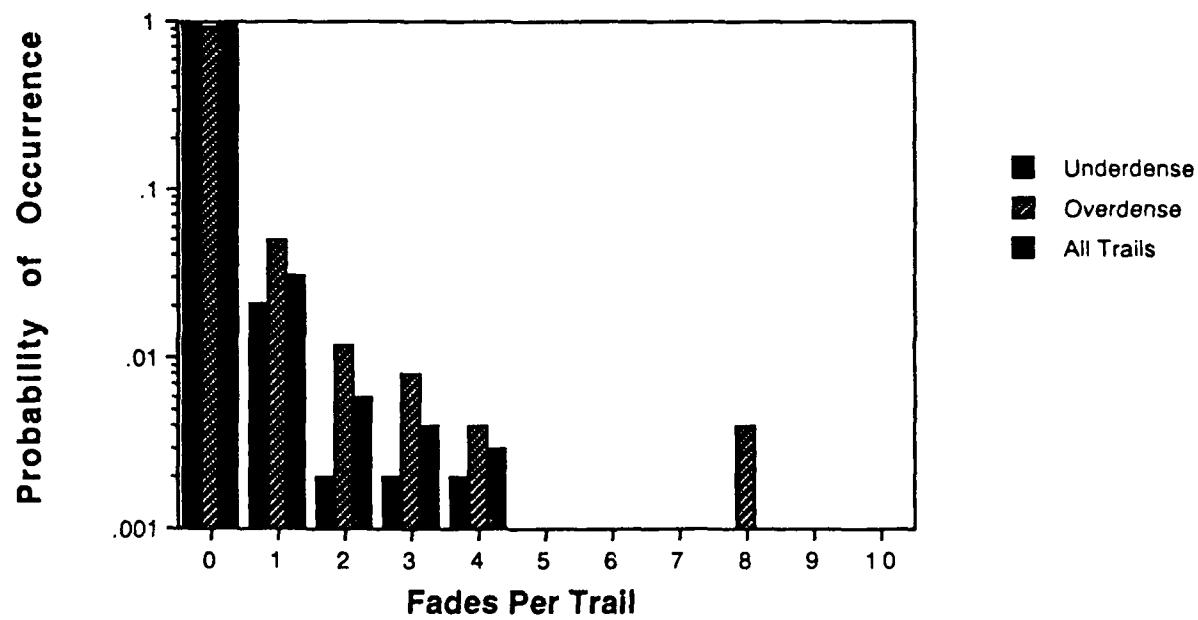
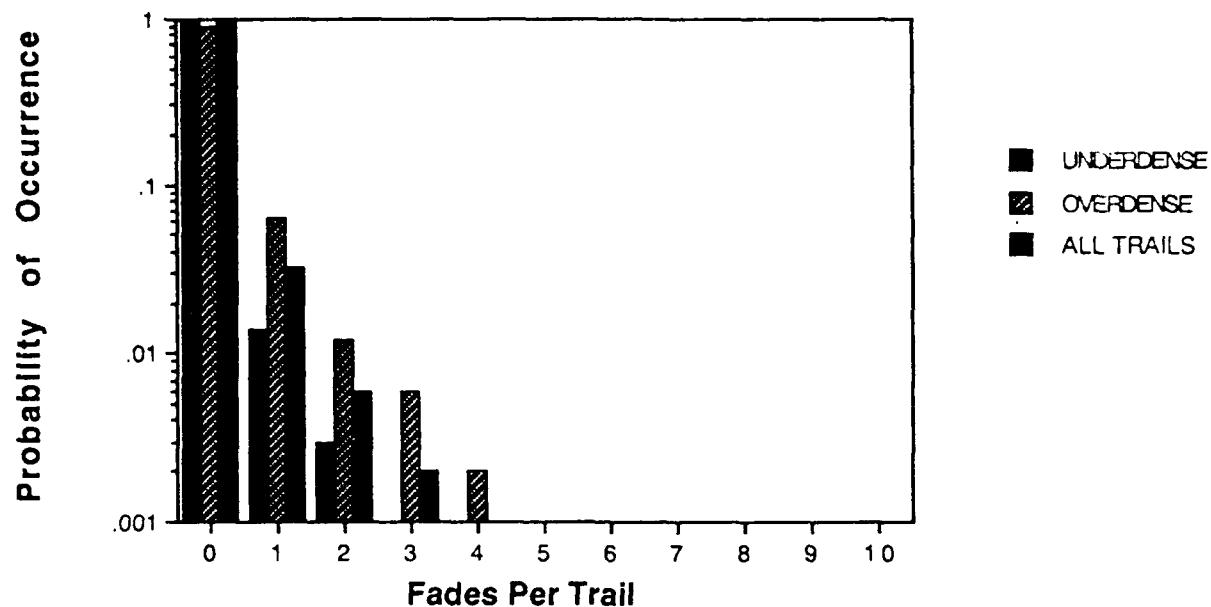


Figure 4. Sondrestrom-Narsarsuaq Link; 100 ms Duration

**Month: April; BW: 8000 Hz; Duration 100 ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km**  
**Sample Size U:3053 O:1783 A:4836**



**Month: April; BW: 8000 Hz; Duration: 100 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km**  
**Sample Size: U: 3053 O: 1783 A: 4836**

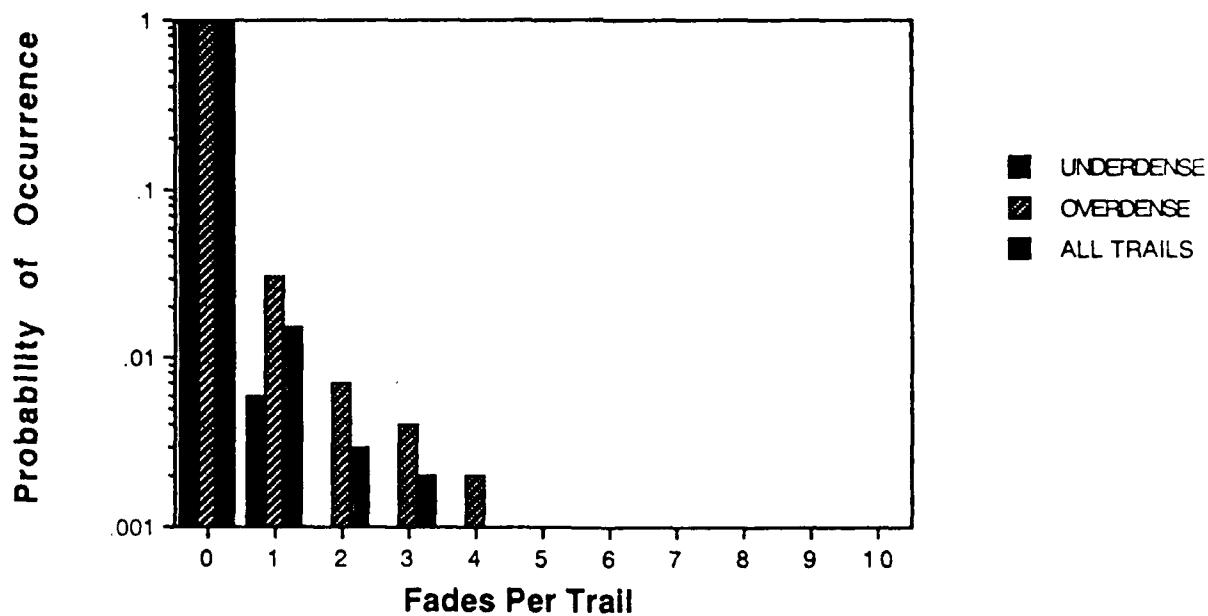
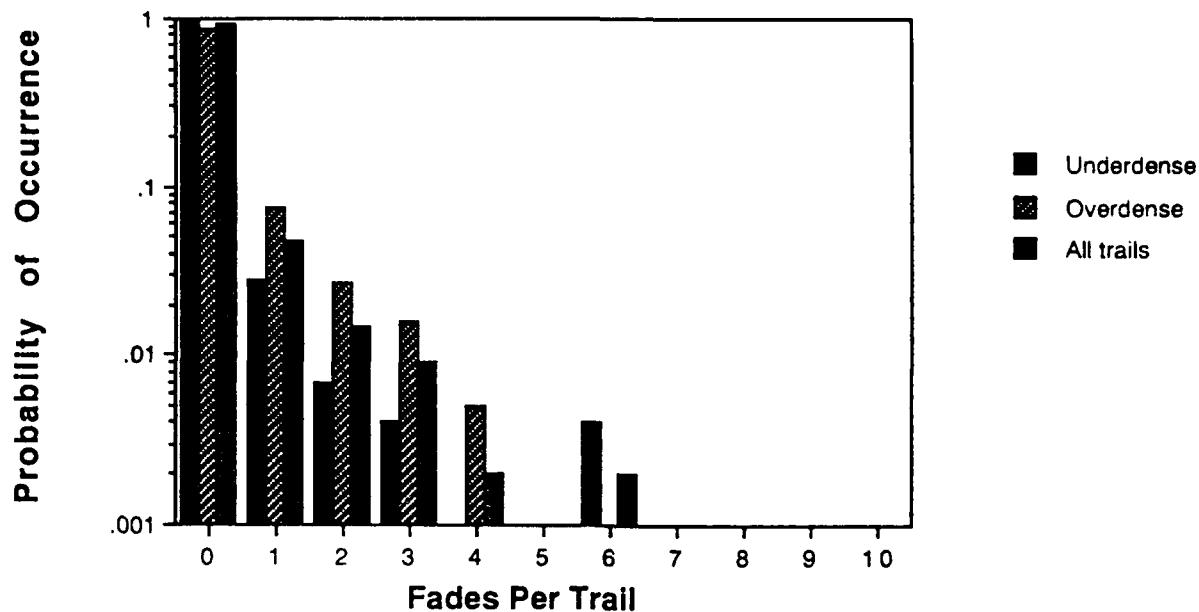


Figure 5. Sondrestrom-Thule Link; 100 ms Duration

**Month: July; BW: 8000 Hz; Duration: 200 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**  
**Sample Size: U:282 O:188 A:470**



**Month: July; BW: 8000 Hz; Duration: 200 ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**  
**Sample Size: U:282 O:188 A:470**

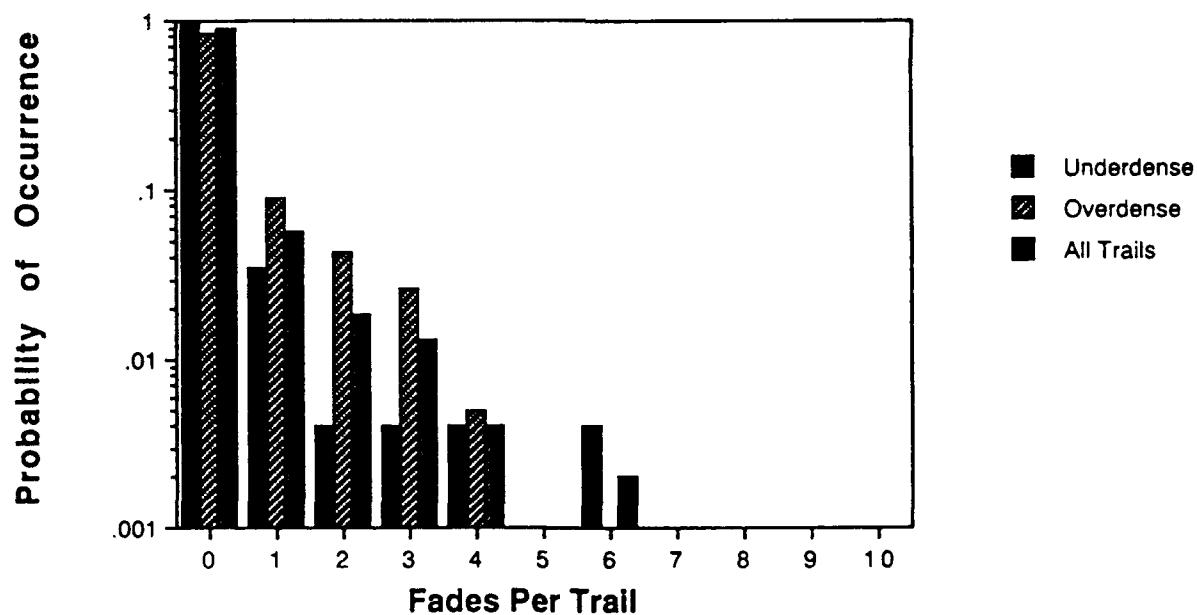
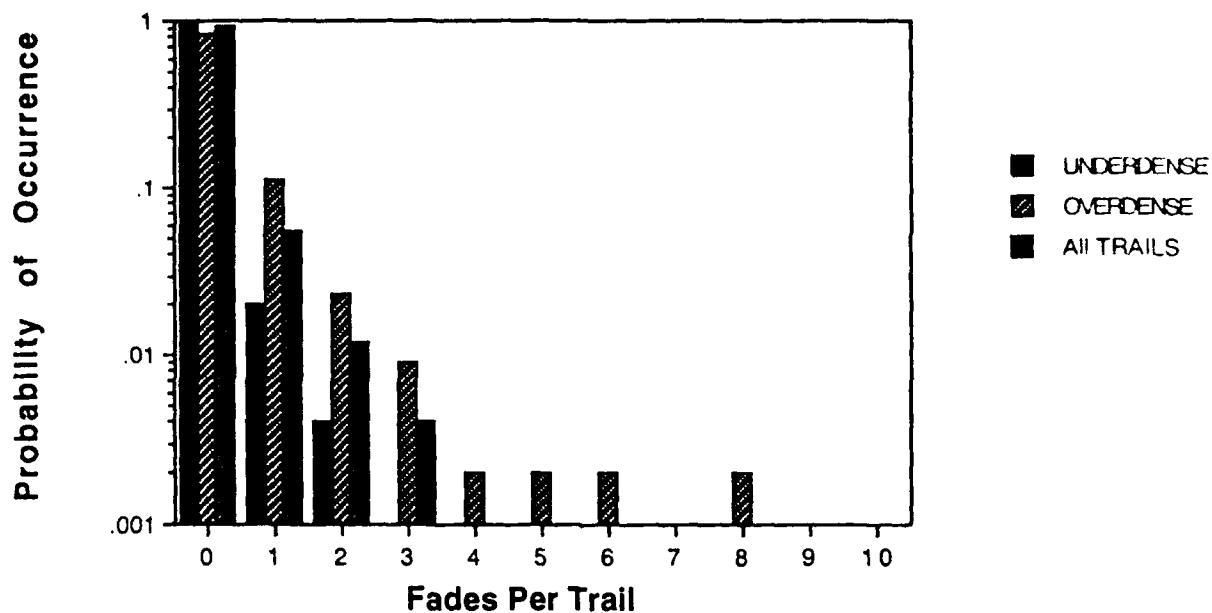


Figure 6. Sondrestrom-Narsarsuaq Link; 200 ms Duration

**Month: April; BW: 8000 Hz; Duration: 200 ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km**  
**Sample Size: U:2074 O:1320 A:3394**



**Month: April; BW:8000 Hz; Duration: 200 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link:1210 km**  
**Sample Size: U:2074 O:1320 A:3394**

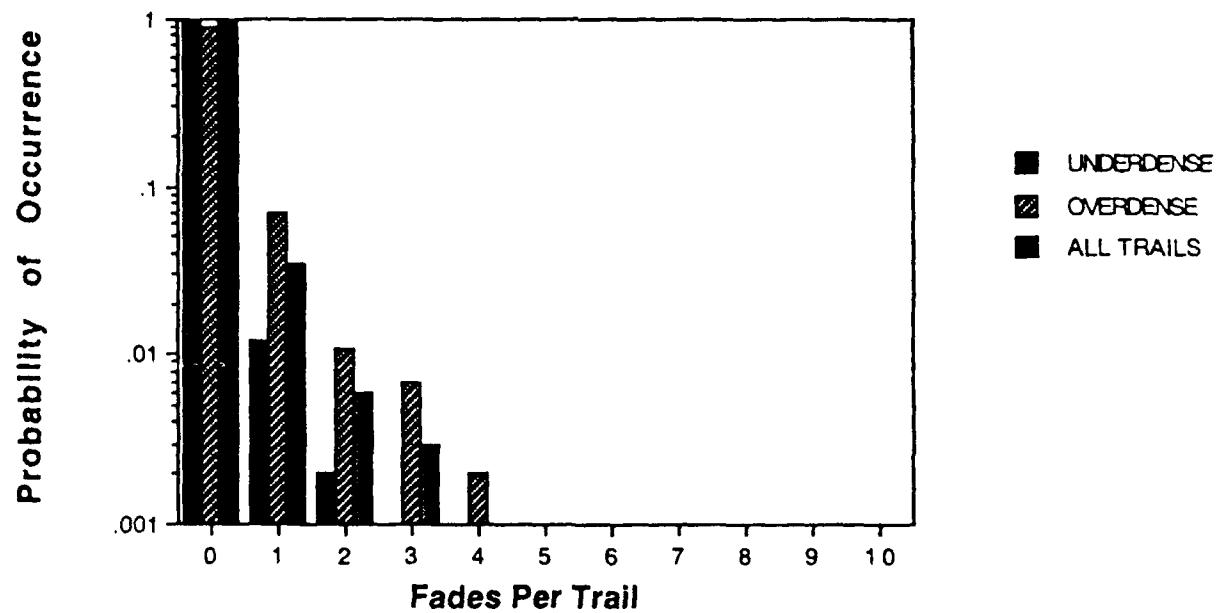
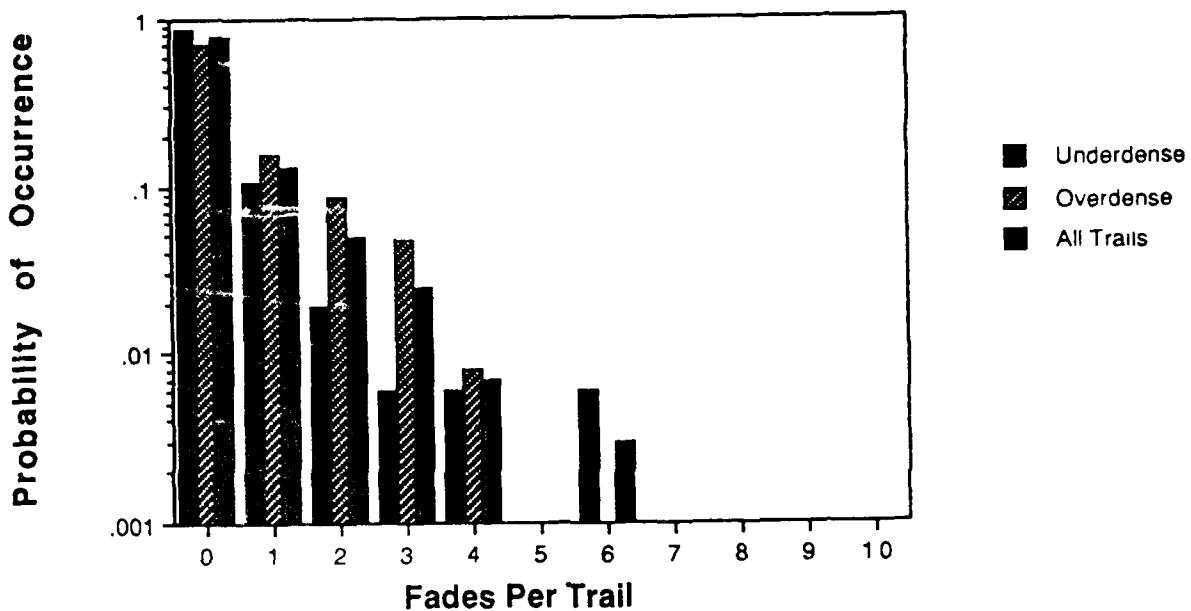


Figure 7. Sondrestrom-Thule Link; 200 ms Duration

**Month: July; BW: 8000 Hz; Duration: 400 ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**  
**Sample Size: U:160 O:127 A:287**



**Month: July; BW: 8000 Hz; Duration: 400 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**  
**Sample Size: U:160 O:127 A:287**

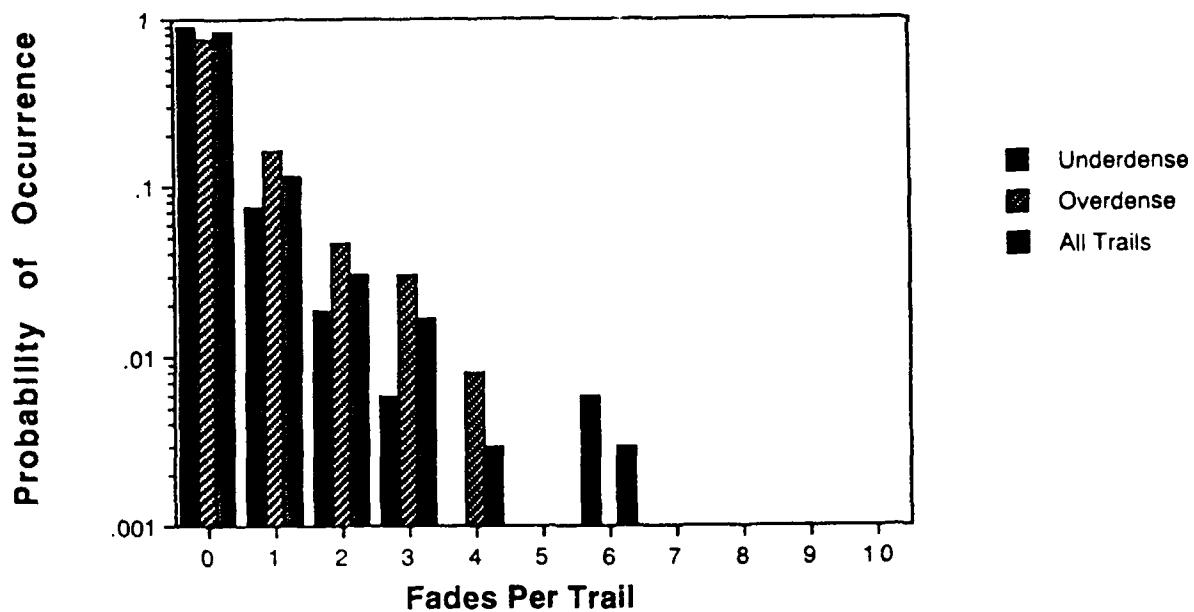
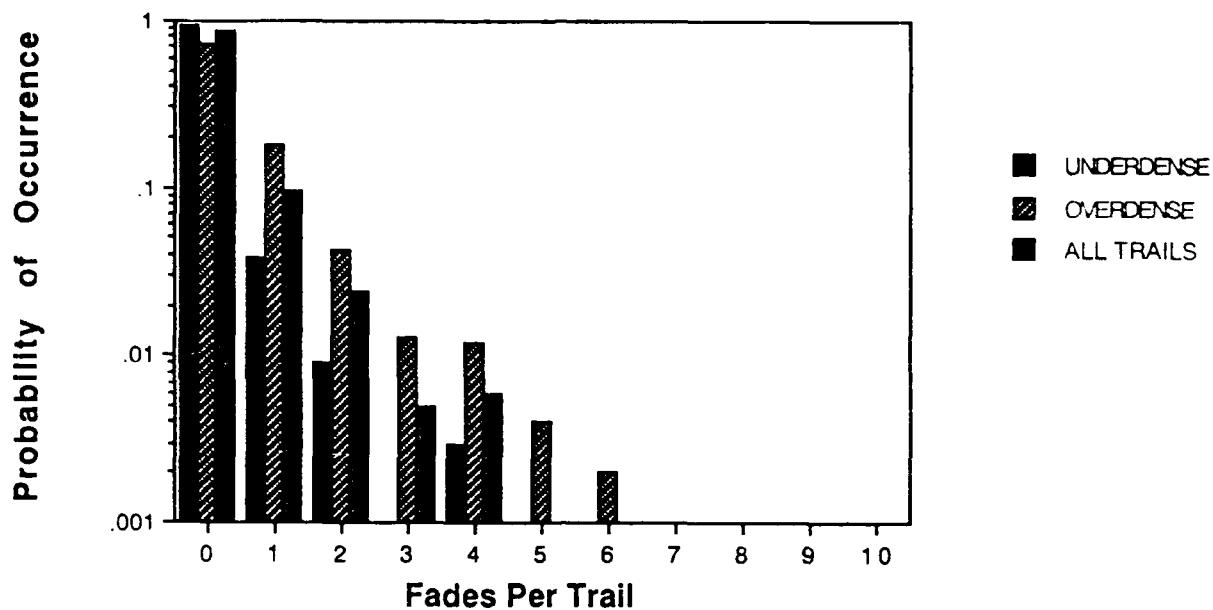


Figure 8. Sondrestrom-Narsarsuaq Link; 400 ms Duration

**Month: April; BW: 8000 Hz; Duration: 400ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km**  
**Sample Size: U: 1161; O: 854 A: 2015**



**Month: April; BW:8000 Hz; Duration: 400 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km**  
**Sample Size: U:1161 O:854 A:2015**

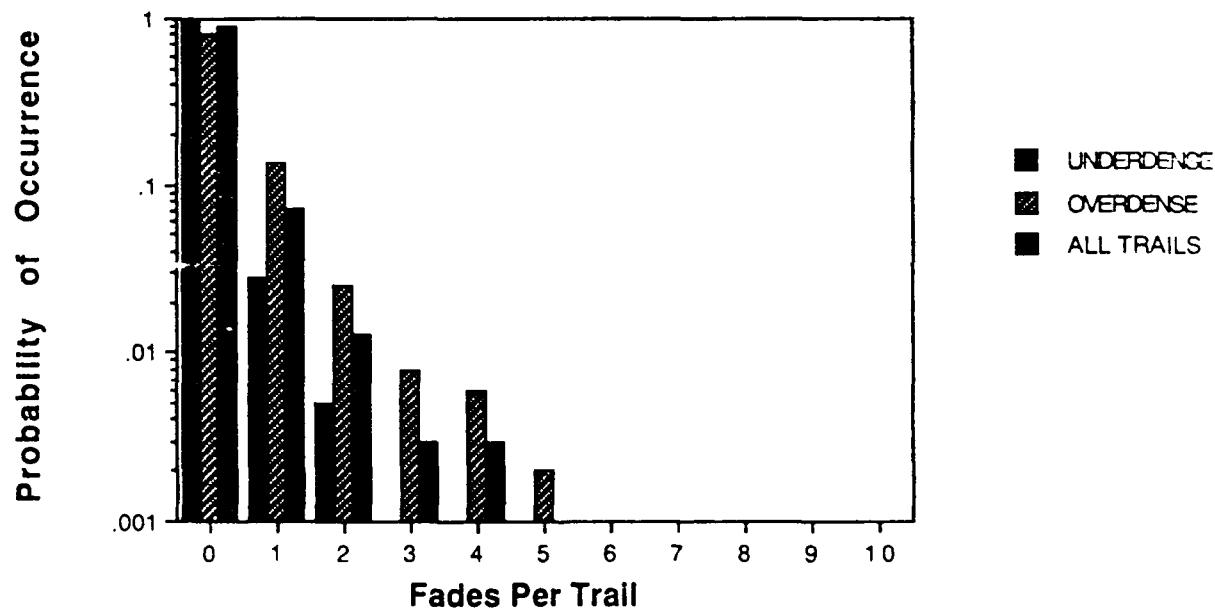
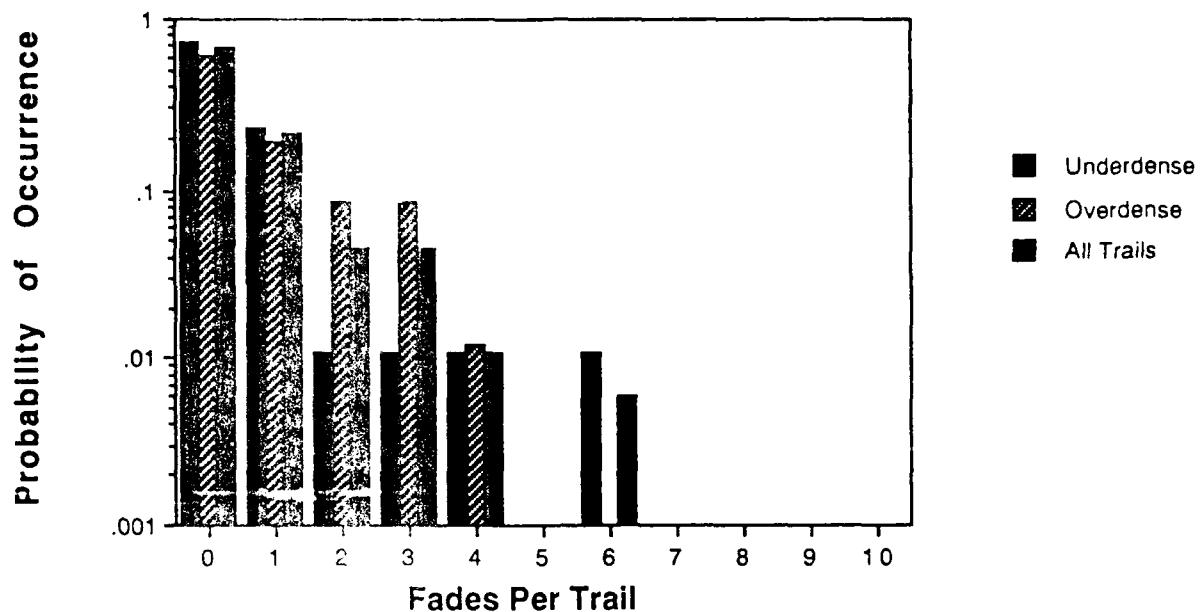


Figure 9. Sondrestrom-Thule Link; 400 ms Duration

**Mo: 15; July; BW: 8000 Hz; Duration: 600 ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fade; Link: 690 km**  
**Sample Size; U:93 O:82 A:175**



**Month: July; BW: 3000 Hz; Duration: 600 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**  
**Sample Size: U:93 O:82 A: 175**

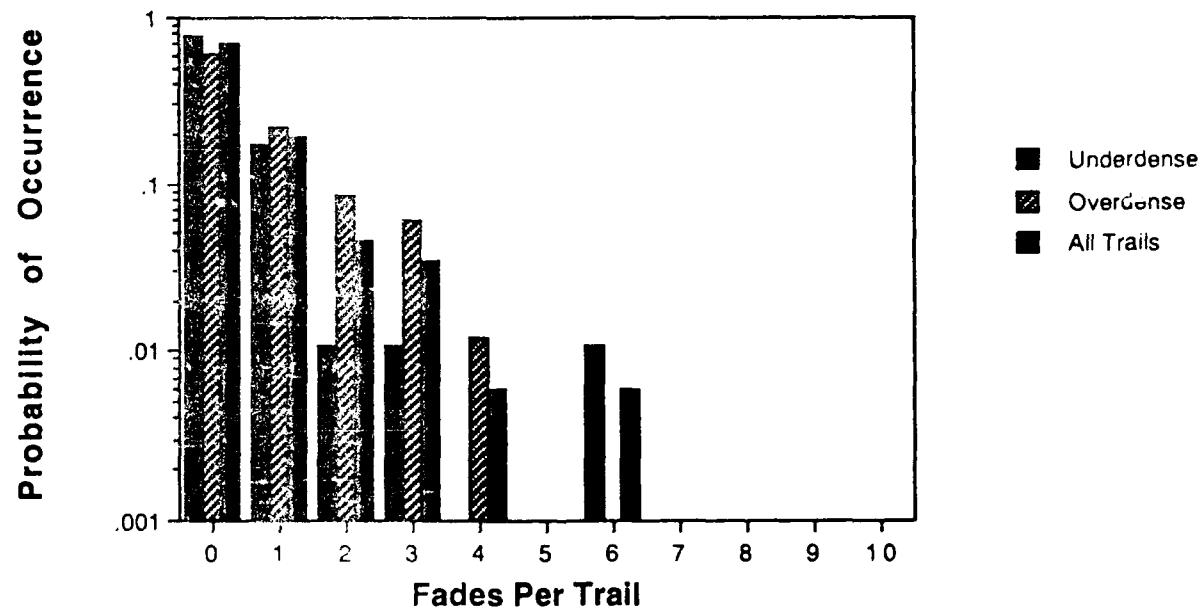
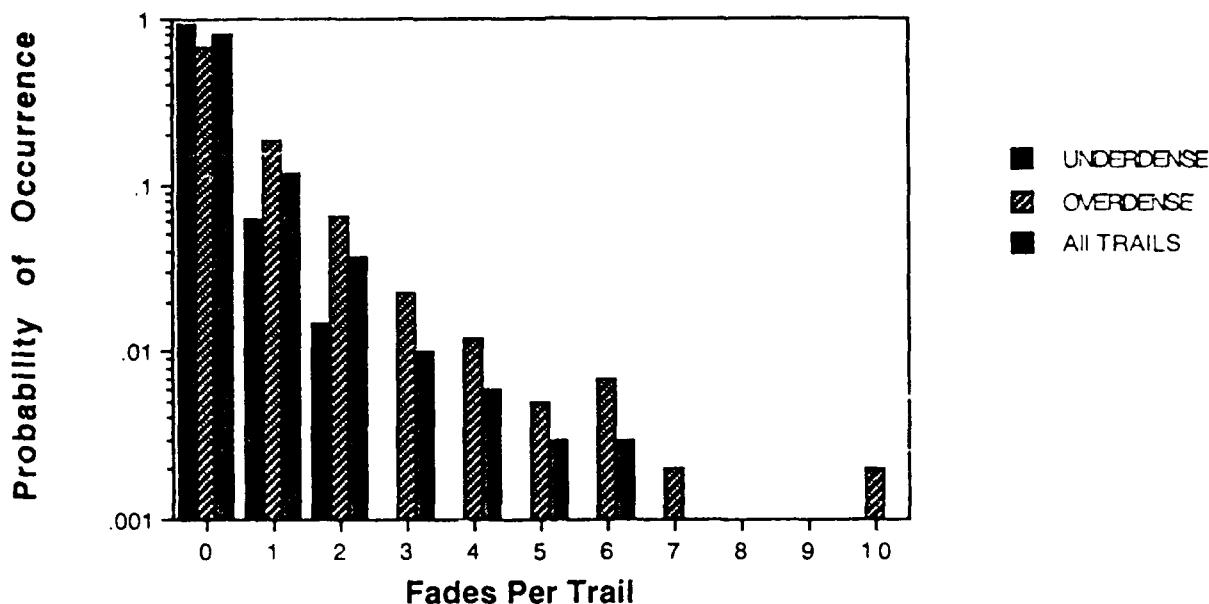


Figure 10. Sondrestrom-Narsarsuaq Link; 600 ms Duration

**Month: April; BW:8000 Hz; Duration: 600ms;**  
**Fade Depth: 6 dB; Freq: 45 MHz; Fast Fade; Link: 1210 km**  
**Sample Size: U:735 O:575 A:1310**



**Month: April; BW:8000 Hz; Duration: 600 ms;**  
**Fade Depth: 9 dB; Freq: 45 MHz; Fast Fade; Link: 1210 km**  
**Sample Size: U:735 O:575 A:1310**

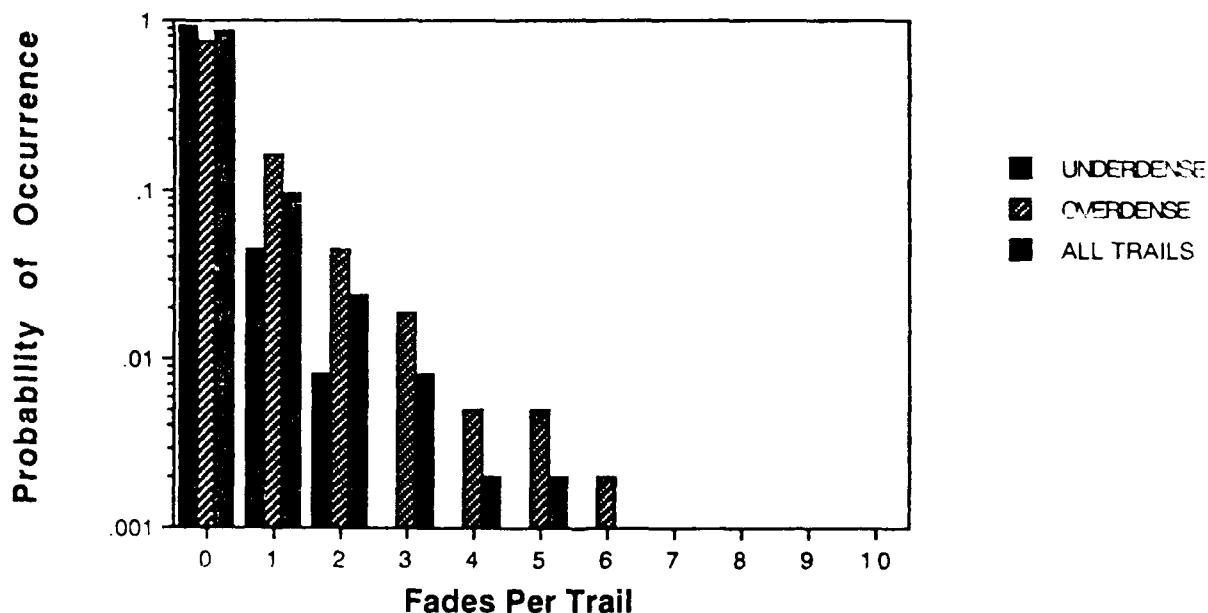


Figure 11. Sondrestrom-Thule Link; 600 ms Duration

Tables 1 and 2 summarize the results in terms of the percentage of trails which are underdense or overdense, the percentage of underdense trails exhibiting fading, the percentage of overdense trails exhibiting fading, and the percentage of all trails exhibiting fading. Statistics are computed for fade depths of 6 and 9 dB and are computed for both links.

Table 1. Summary of Results for July 1990: Sondrestrom-Narsarsuaq Link

Duration	6 dB Fades				
	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	69	31	1	7	3
100	63	37	3	12	6
200	60	40	5	17	10
400	56	44	14	30	21
600	53	47	27	38	32

Duration	9 dB Fades				
	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	69	31	1	5	2
100	63	37	2	8	4
200	60	40	4	12	7
400	56	44	10	25	17
600	53	47	20	28	29

Table 2. Summary of Results for April 1990: Sondrestrom-Thule Link

6 dB Fades					
Duration	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	67	33	1	5	2
100	63	37	1	8	4
200	61	39	2	15	7
400	57	43	5	215	14
600	55	45	8	31	28

9 dB Fades					
Duration	%und	%ovd	%und-fad	%ovd-fad	%all fad
50	67	61	0	3	1
100	63	63	0	4	2
200	61	39	3	8	5
400	57	43	3	18	10
600	55	45	5	24	14

Table 3 summarizes the results for the low resolution experiment for trails of 100 ms duration for the Sondrestrom-Thule line and we see that the results are consistent with Table 2.

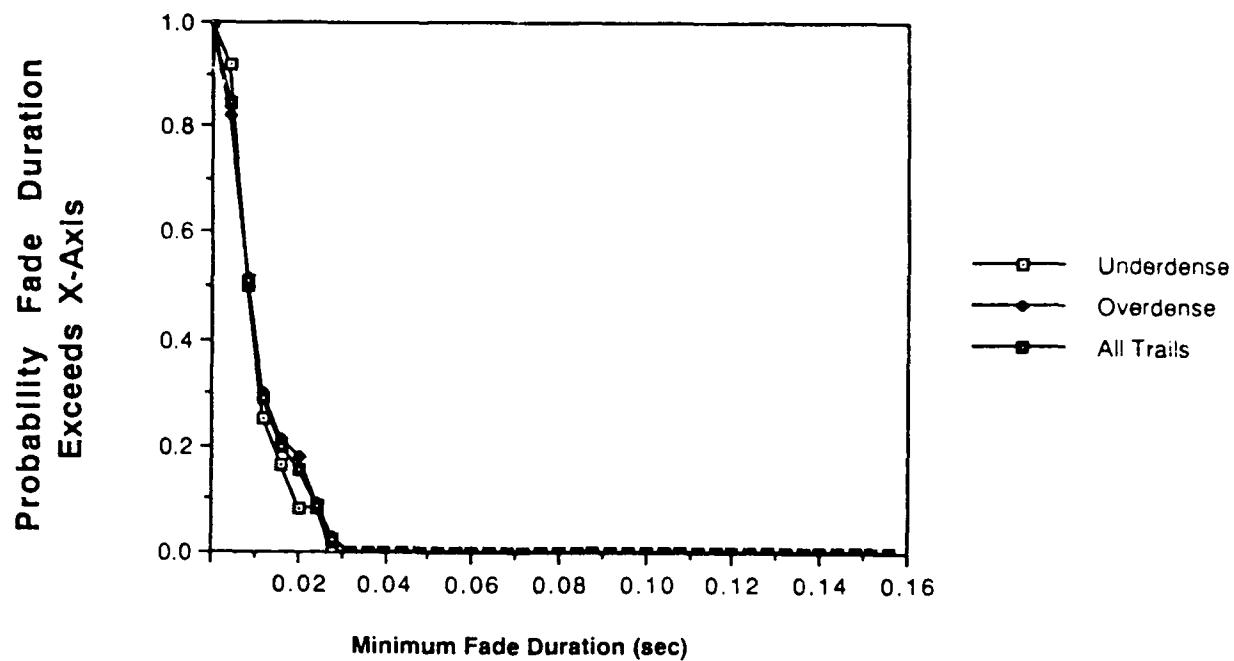
Month(1989)	% und	%ovr	%und-fad	%ovr-fad	%all-fad
Mar	51	49	1	2	1
Jun	37	63	1	4	3
Sep	50	50	1	4	2
Dec	48	52	1	4	2

Table 3. Summary of Results for Low Resolution Experiment

For both links, a second set of plots has been generated, as presented in Figures 12 through 16. This set plots the cumulative probability distribution function of each fade observed in the set. Recall that there can be more than one fade per trail. The X-axis plots the duration of the fade and the Y axis plots the probability that the duration of the fade exceeds the x-axis.

As expected, the duration of fades increases as the depth of the fade is increased.

**Month: July; BW:8000 Hz; Duration: 50 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**



**Month: April; BW:8000 Hz; Duration: 50 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fade; Link: 1210 km**

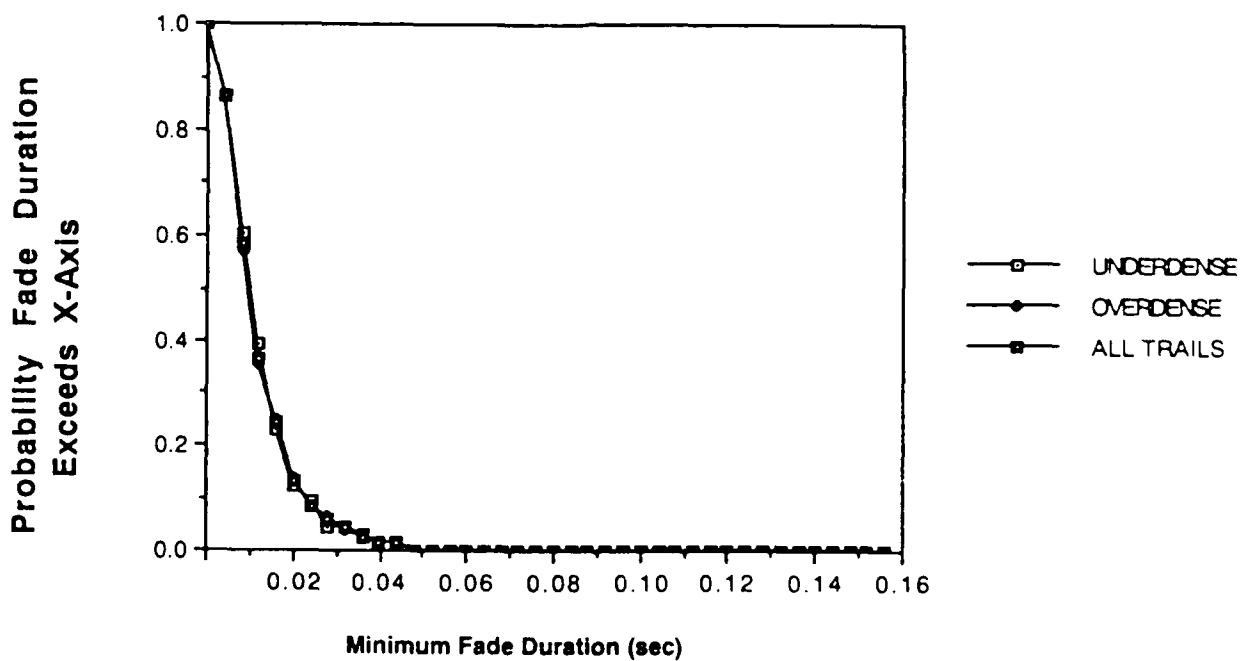
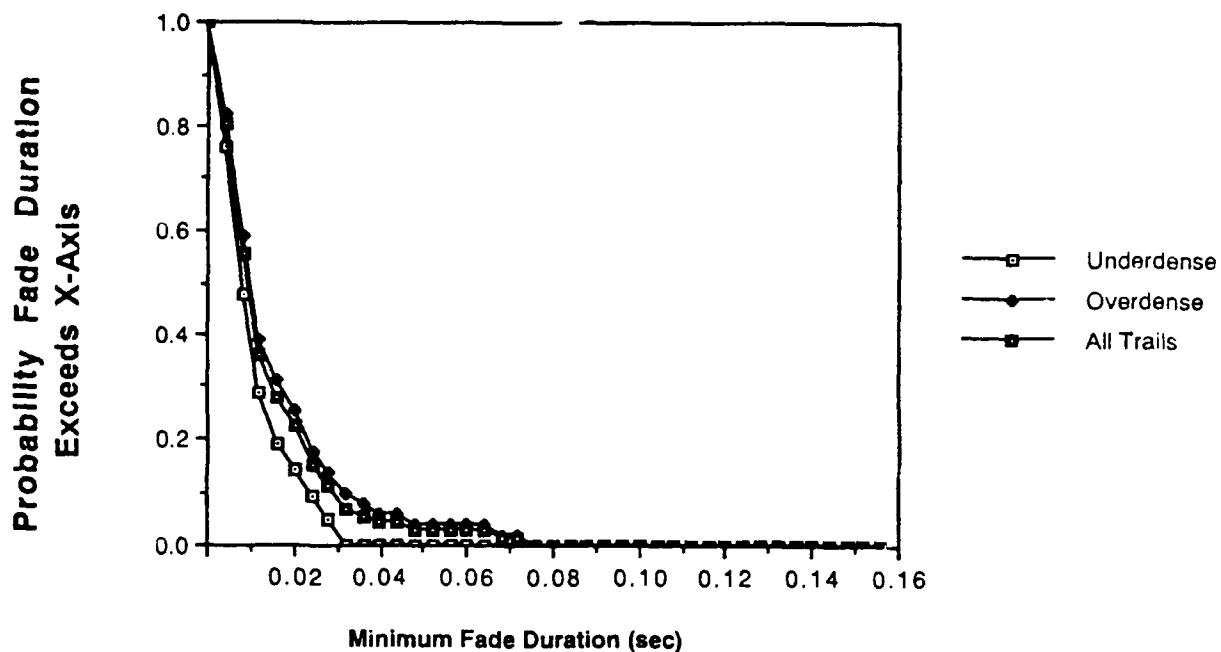


Figure 12. Cumulative Probability Distribution Function; 50 ms Duration

Month: July; BW: 8000 Hz; Duration: 100 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km



Month: April; BW: 8000 Hz; Duration 100 ms;  
Fade Depth 6 dB; Freq: 45 MHz; Fast Fade; Link: 1210 km

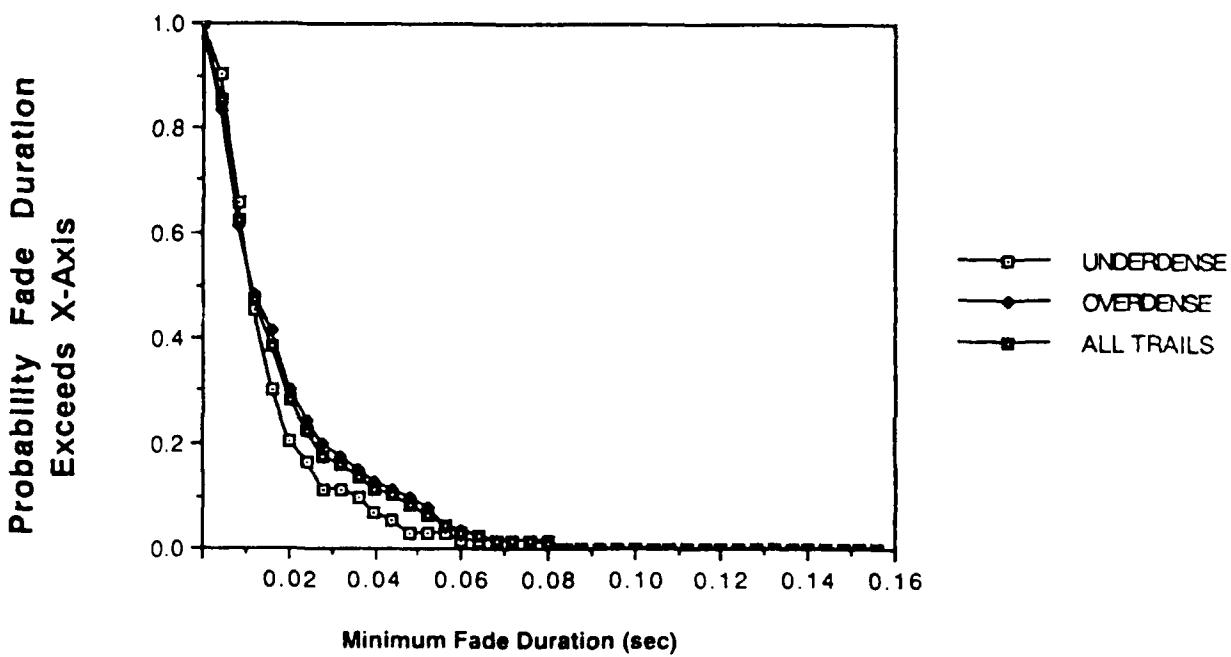
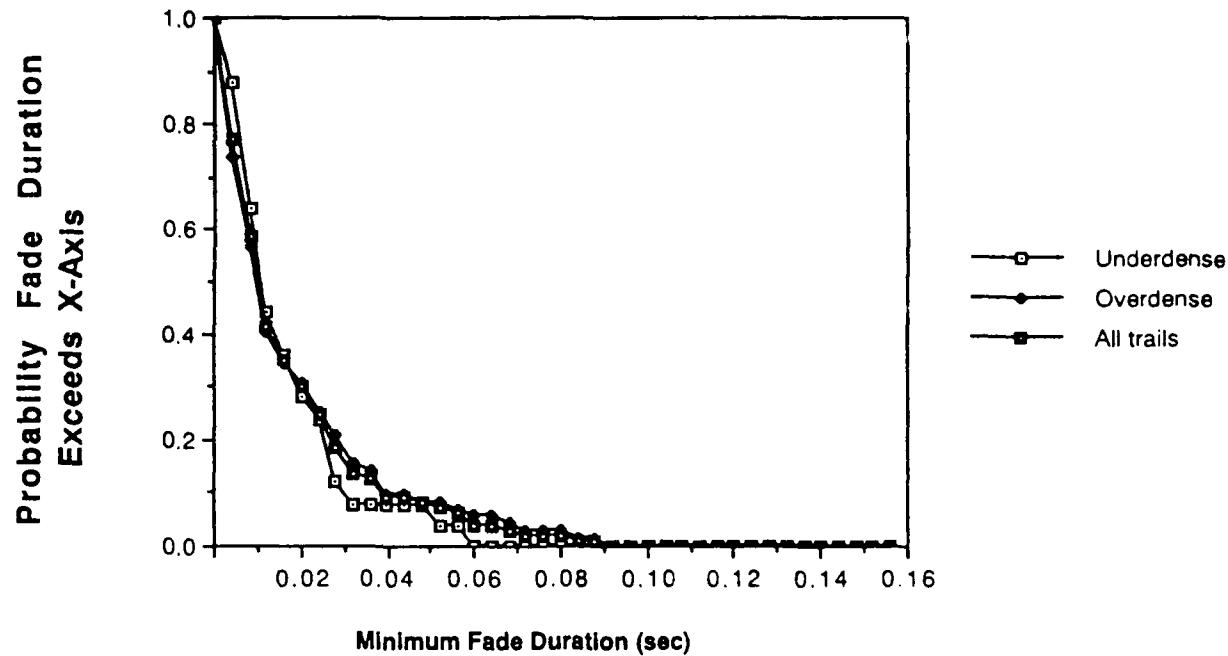


Figure 13. Cumulative Probability Distribution Function; 100 ms Duration

**Month: July; BW:8000 Hz; Duration: 200 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**



**Month: April; BW: 8000 Hz; Duration 200 ms;  
Fade Depth: 6 dB; Freq: 45 MHz;Fast Fading; Link:1210 km**

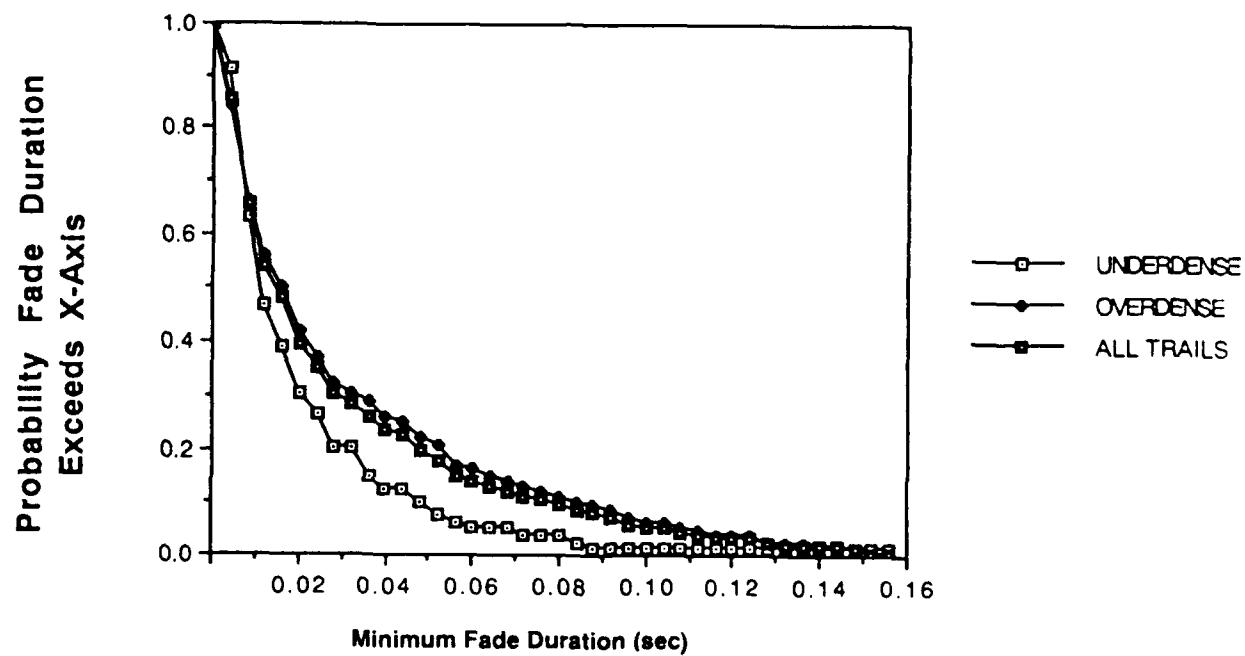
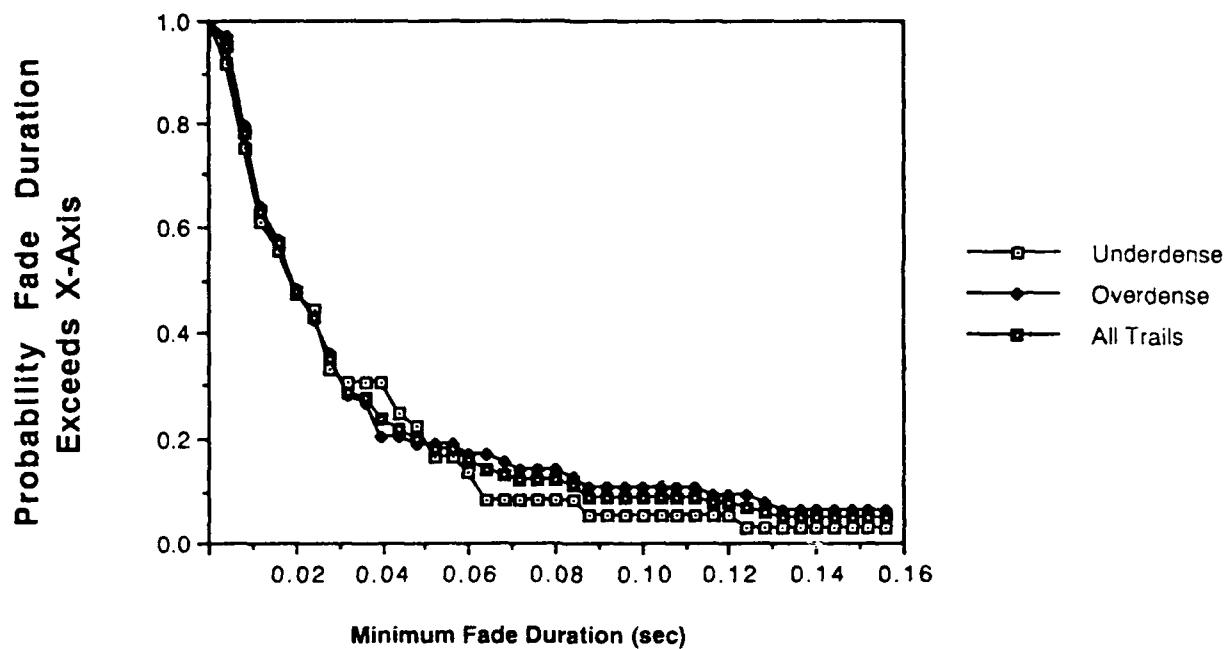


Figure 14. Cumulative Probability Distribution Function; 200 ms Duration

**Month: July; BW: 8000 Hz; Duration: 400 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km**



**Month: April; BW: 8000 Hz; Duration: 400 ms;  
Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 1210 km**

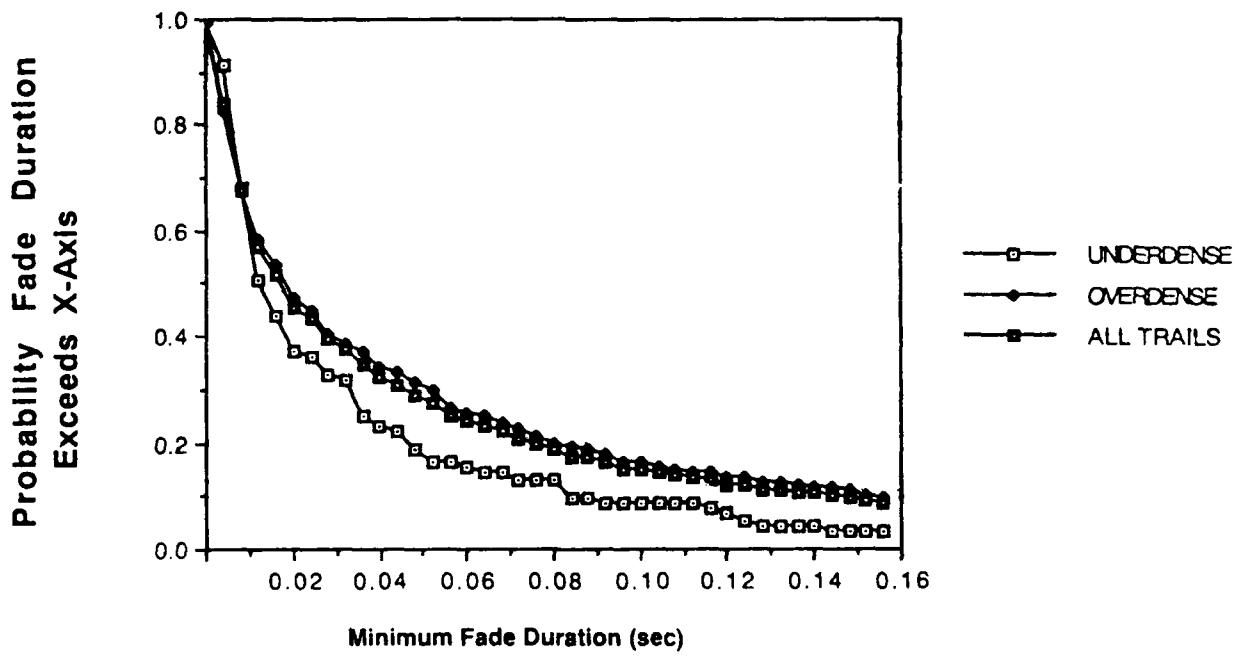
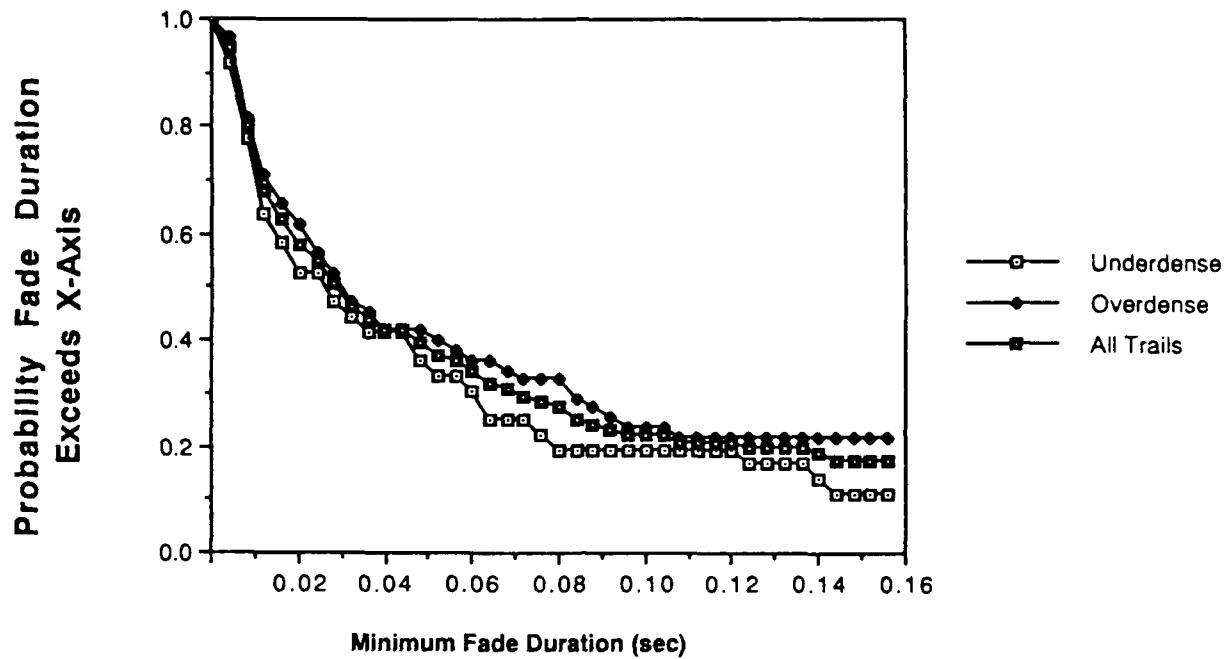


Figure 15. Cumulative Probability Distribution Function; 400 ms Duration

Month: July; BW: 8000 Hz; Duration: 600 ms;  
 Fade Depth: 6 dB; Freq: 45 MHz; Fast Fading; Link: 690 km



Month: April; BW: 8000 Hz; Duration: 600 ms;  
 Fade Depth: 6 dB; Freq: 45 MHz; Fast Fade; Link: 1210 km

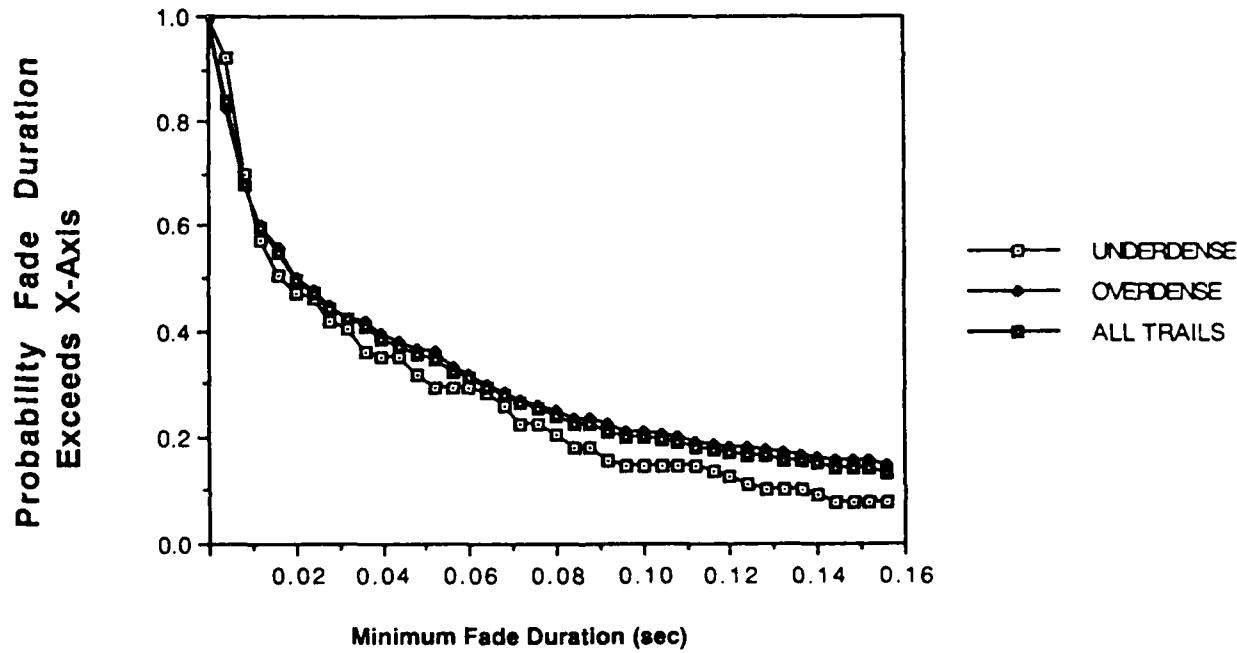


Figure 16. Cumulative Probability Distribution Function; 600 ms Duration

### 3.0 DISCUSSION

In the two high resolution data sets, the trends were for the most part consistent with the previous lower resolution experiment. The primary difference observed was in the percentage of trails classified as underdense and overdense. Data from the fast fade experiment tended to show more underdense trails as opposed to the slow fade data.

In terms of percentages of trails showing fading, the results were very consistent between the two different data sets. As expected due to the lower noise margin and the ability to resolve the fine structure of the trails, the percent of trails showing fading was slightly higher for the higher resolution experiment. At trail durations less than 200 ms, the conclusion from the first experiment that the effect of fading is minimal is confirmed.

Consider 100 ms trails at 45 MHz with 6 dB fade depths. For the most part the percentage of underdense trails in which fading was observed was on the order of 1 percent for both the high and low resolution experiments. For the entire trail set between 1 and 4 percent of the trails at 45 MHz showed 6 dB or greater fades. See Table 4.

Table 4. Comparison of High Resolution and Low Resolution Data for 100 ms Duration Trails.

Month(1989)	% und	%ovr	%und-fad	%ovr-fad	%all-fad
Mar	51	49	1	2	1
Jun	37	63	1	4	3
Sep	50	50	1	4	2
Dec	48	52	1	4	2
Apr*	63	37	1	8	4

\* denotes high resolution data

At 200 ms duration the results were similarly consistent. Approximately 2 percent of the underdense trails exhibited fading and approximately 8 percent of all the trails showed fading. See Table 5.

Table 5. Summary of High and Low Resolution Measurements for Trails of 200 ms Duration.

Month (1989)	% und	%ovr	%und-fad	%ovr-fad	%all-fad
Mar	49	51	1	6	3
Jun	35	65	2	7	5
Sep	46	54	2	10	7
Dec	43	57	3	11	7
Apr*	61	39	2	15	7

In the analysis of the data several definite trends emerge. Underdense trails tend to show less fading than overdense trails. This was consistent between the two experiments. As the trail duration increases, the probability of fading increases. As expected, as the trail duration increases, the percentage of underdense trails decreases. As signal level increases, the percentage of underdense trails decreases so the percent of trails with fading will increase. As expected from the analysis of Manning, wind induced effects become apparent at about 400 ms trail duration at which the percentage and depth of fades increases. For long duration trails (defined as those exceeding approximately 250 ms), model predictions must be made more pessimistic to take into account the effects of fading.

Analysis showed that approximately 50% of the fade durations were less than 20 ms. Given the distribution of fades, techniques such as interleaving combined with forward error correction coding can be very effective in combatting the effect of the fades.

#### 4.0 REFERENCES

Ahmad, K. A., A. Javed and M. D. Grossi, "Adaptive Communications via Meteor Forward Scattering," Pakistan International Symposium on Electrical Engineering, November 15-17, 1972, Lahore, West Pakistan, 1972.

Akram, F., A. Sheik, A. Javed and G. M. D., "Impulse Response of a Meteor Burst Communications Channel Determined By Ray-Tracing Techniques," IEEE Trans. on Comm., 467-471, 1977.

Carpenter, R. J. and G. R. Ochs, "High Resolution Pulse Measurements of Meteor-Burst Propagation at 41 Mc/s Over a 1295-km Path," NBS J. Res., 66D, 249-263, 1962.

Greenhow, J. S. and E. L. Neufeld, "Turbulence at altitudes of 80-100 km and its effects on long-duration meteor echoes," J. Atmos. and Terr. Phys., 16, 384-392, 1959.

Grossi, M. D. and A. Javed, "Time and frequency spread in meteor burst propagation paths," AGARD-Electromagnetic Wave Propagation Panel, 23rd Symposium on Aspects of EM Wave Scattering in Radio Communications, Cambridge, MA, 1977.

Hawkins, G. S. and D. F. Winter, "Radar echoes from overdense meteor trails under conditions of severe diffusion," Proc. IRE, 45, 1290-1291, 1957.

Manning, L. A., "Air Motions and the Fading, Diversity, and Aspect Sensitivity of Meteoric Echoes," J. Geophys. Res., 64, 1415-1425, 1959.

Sugar, G. R., R. J. Carpenter and G. R. Ochs, "Elementary considerations of the effects of multipath propagation in meteor-burst communication," J. Research NBS, 64D, 495-500, 1960.

Weitzen, J. A., "Characterizing the Multipath and Doppler Profiles of the High Latitude Meteor Scatter Channel," RADC-TR-86-165, Rome Air Development Center, ADA174672, October 1986.

Weitzen, J. A., M. D. Grossi and W. P. Birkemeier, "High-resolution Multipath Measurements of the Meteor Scatter Channel," Radio Sci., 19, 375-381, 1984.

Weitzen, J. A., M. J. Sowa, Q. J. and R. A. Scofidio, "Characterizing the Multipath and Doppler Profiles of the Meteor Burst Communication Channel," IEEE Trans. on Comm., 35, 1050-1058, 1987.

Weitzen, J.A., and S. Tolman, "A technique for automatic classification of meteor trails and other propagation mechanisms for the Air Force High Latitude Meteor Scatter Test Bed," RADC Technical Report RADC-TR-86-117, ADA173133, September 1986.

Weitzen, J. A. "An improved technique for automatic classification of meteor trails and other propagation mechanisms for the Air Force High Latitude Meteor Scatter Test Bed," manuscript in preparation, 1990.

Weitzen, J.A. and J.C. Ostergaard, "Statistical Characterization of Fading on Meteor Scatter Communication Channels," GL-TR-90-0362, December 1990.

-----, GL Report to BMO/MGEC, "Criteria for the Classification of Overdense and Underdense Meteor Scatter Returns From the USAF High Latitude Meteor Scatter Test Bed," 23 March 1990, University of Lowell, Lowell, MA 01854.